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Critical Functions: Needed Roles in the Innovation Process

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CRITICAL FUNCTIONS: NEEDED ROLES IN THE INNOVATION PROCESS

Edward B. Roberts* and Alan R. Fusfeld+

I. INTRODUCTION

This article examines the main elements of the technology-based innovation process in terms of certain usually informal but critical "people" functions that can be the key to an effective organizational base for innovation. This approach to the innovation process is similar to that taken by early industrial theorists who focused on the production process. Led by such individuals as Frederick W. Taylor, their efforts resulted in basic principles for increasing the efficiency of producing goods and services. These principles of specialization, chain of command, division of labor, and span of control continue to govern the operation of the modern organization (despite their shift from popularity in many modern business schools). Hence, routine tasks in most organizations are arranged to facilitate work standardization with expectations that efficient production will result. However, examination of how industry has organized its innovation tasks--that is, those tasks needed for product/process development and for responses to non-routine demands--indicates an absence of comparable theory. And many corporations' attempts to innovate consequently suffer from ineffective management and inadequately staffed organizations. Yet, through tens of studies about the innovation process, conducted largely in the last fifteen years, we now know much about the activities that are requisite to innovation as well as the characteristics of the people who perform these activities most effectively.

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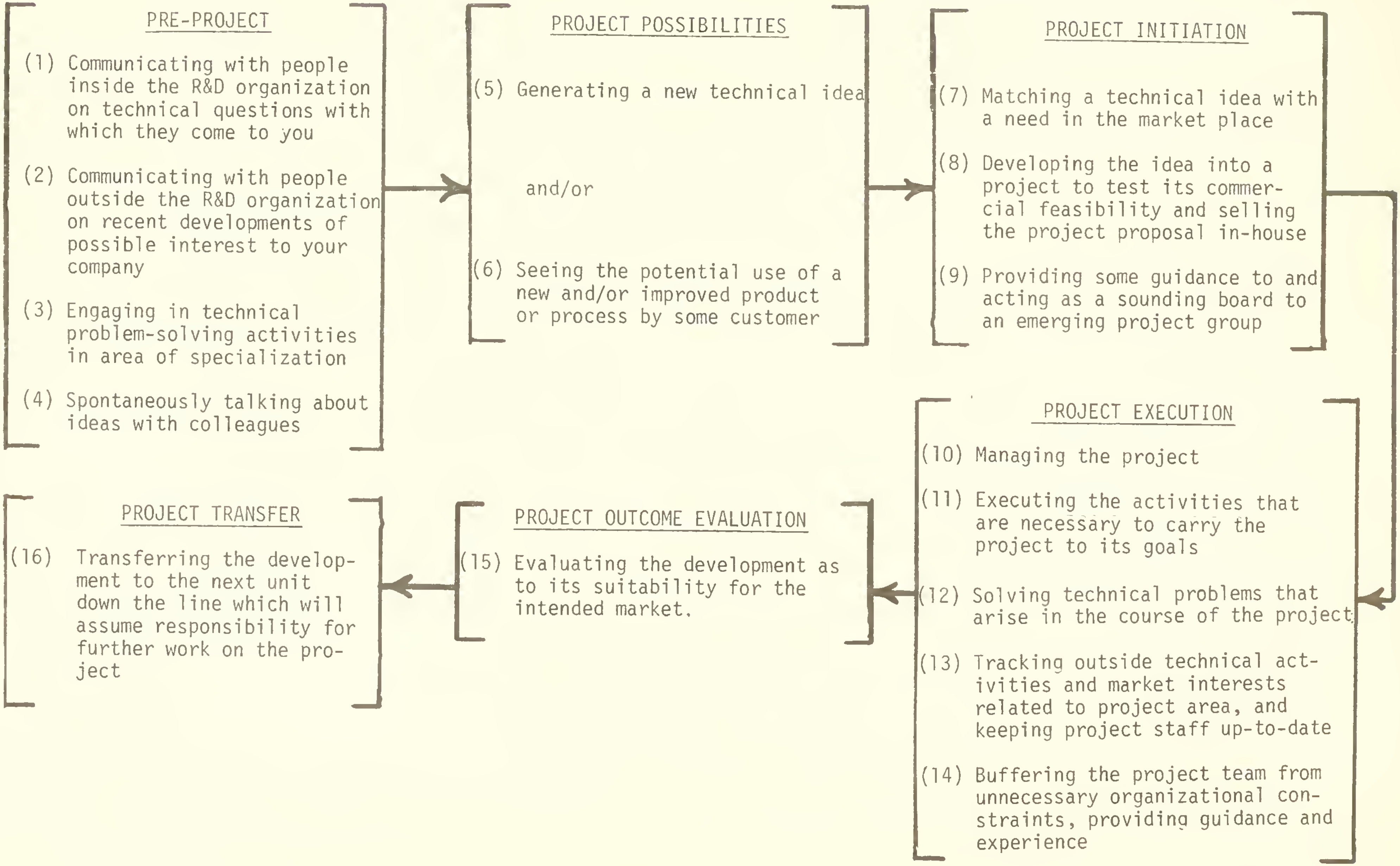
Section II of this article characterizes the technology-based innovation process via a detailed description of a typical research and development project life cycle. The types of work activities arising in each project phase are enumerated. This leads in Section III to the identification of the five basic critical roles that are needed for effective execution of an innovative effort. Problems associated with gaps in the fulfillment of the needed roles are discussed. Detailed characteristics and specific activities that are associated with each role filler are elaborated in the next section. The multiple roles that are sometimes performed by certain individuals are observed, as are the dynamics of role changes that tend to take place over the life span of a productive career. Section V presents several areas of managerial implications of the critical functions concepts, beginning first with issues of manpower planning, then moving to considerations of job design and objective setting and to the determination of appropriate performance measures and rewards. How an organizational assessment can be carried out in terms of these critical functions dimensions is discussed in Section VI, with the illustrative description of one such assessment in a medium-sized research and development organization. The final paragraphs synopsize the article and indicate the transferability of critical functions concepts to other kinds of organizations.

II. THE INNOVATION PROCESS

The major steps involved in the technology-based innovation process are shown in Figure 1. Although the project activities do not necessarily follow each other in a linear fashion, there is more-or-less clear demarcation between them. Each stage, moreover, and its activities, require a different mix of people skills and behaviors to be carried out effectively.

Figure 1. A Multi-Stage View of a Technical Innovation Project



PRE-PROJECT

(1) Communicating with people inside the R&D organization on technical questions with which they come to you

(2) Communicating with people outside the R&D organization on recent developments of possible interest to your company

(3) Engaging in technical problem-solving activities in area of specialization

(4) Spontaneously talking about ideas with colleagues

PROJECT POSSIBILITIES

(5) Generating a new technical idea

and/or

(6) Seeing the potential use of a new and/or improved product or process by some customer

PROJECT INITIATION

(7) Matching a technical idea with a need in the market place

(8) Developing the idea into a project to test its commercial feasibility and selling the project proposal in-house

(9) Providing some guidance to and acting as a sounding board to an emerging project group

PROJECT EXECUTION

(10) Managing the project

(11) Executing the activities that are necessary to carry the project to its goals

(12) Solving technical problems that arise in the course of the project

(13) Tracking outside technical activities and market interests related to project area, and keeping project staff up-to-date

(14) Buffering the project team from unnecessary organizational constraints, providing guidance and experience

PROJECT OUTCOME EVALUATION

(15) Evaluating the development as to its suitability for the intended market.

PROJECT TRANSFER

(16) Transferring the development to the next unit down the line which will assume responsibility for further work on the project

The figure portrays six stages as occurring in the typical technical innovation project, and sixteen representative activities that are associated with innovative efforts. The six stages are here identified as:

(1) Pre-project

(2) Project possibilities

(3) Project initiation

(4) Project execution

(5) Project outcome evaluation

(6) Project transfer

These stages often overlap and frequently recycle.[1] For example, problems or findings that are generated during project execution may cause a return to project initiation activities. Outcome evaluation can restart additional project execution efforts. And, of course, project cancellation can occur during any of these stages, redirecting technical endeavors back into the pre-project phase.

A variety of different activities are undertaken during each of the six stages. Some of the activities, such as generating new technical ideas, arise in all innovation project stages from pre-project to project transfer. But our research studies and consulting efforts in dozens of companies and government labs have shown other activities to be concentrated mainly in specific stages, as discussed below.

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[1] For a different and more intensive quantitative view of project life cycles, see Edward B. Roberts, The Dynamics of Research and Development (New York: Harper & Row, 1964).

(1) Pre-Project. Prior to formal project activities being undertaken in a technical organization, considerable technical work is done that provides a basis for later innovation efforts. Scientists, engineers and marketing people find themselves involved in discussions internal and external to the organization. Ideas get discussed in rough-cut ways and broad parameters of innovative interests get established. Technical personnel work on problem-solving efforts to advance their own areas of specialization. Discussions with numerous industrial firms in the U.S. and Europe suggest that from 30 to 60 percent of all technical effort is devoted to work outside of or prior to formal project initiation.

(2) Project Possibilities. Arising from the preproject activities, specific ideas are generated for possible projects. They may be technical concepts for assumed-to-be-feasible developments. Or they may be perceptions of possible customer interests in product or process changes. Customer-oriented perspectives may be originated by technical or marketing or managerial personnel out of their imagination or from direct contact with customers or competitors. Recent evidence indicates that many of these ideas enter as "proven" possibilities, having already been developed by the customers themselves.[2]

(3) Project Initiation. As ideas evolve and get massaged through technical and marketing discussions and exploratory technical efforts, the innovation process moves into a more formal project initiation stage. Activities occurring during this phase include attempts to match the directions of technical work with perceived customer needs. (Of course, such customer needs may exist either in the production organization or in the product marketplace.) In-

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[2] Eric von Hippel, "Users as Innovators". Technology Review, 80, No. 3 (January 1978), 30-39.

evitably, a specific project proposal has to be written up, proposed budgets and schedules get produced, and informal pushing as well as formal presentations have to be undertaken in order to sell the project. A key input during this stage is the counselling and encouragement that senior technical professionals or lab and marketing management may provide to the emerging project team.

(4) Project Execution. With formal approval of a project aimed at an innovative output, activities increase in intensity and focus. In parallel, someone usually undertakes planning, leadership and coordinating efforts related to the many continuing technical idea-generating and problem-solving activities being done by the engineers and scientists assigned to the project. Technical people often make special attempts to monitor (and transfer in) what had been done previously as well as what is then going on outside the project that is relevant to the project's goals. Management or marketing people frequently take a closer look at competitors and customers to be sure the project is appropriately targeted.[3] Senior people try to protect the project from overly tight control or from getting cut off prematurely, and the project manager and other enthusiasts keep fighting to defend their project's virtues (and budget). Unless cancelled, the project work continues toward completion of its objectives.

(5) Project Outcome Evaluation. When the technical effort seems complete, most projects undergo another often intense evaluation to see how the results stack up against prior expectations and current market perceptions. If a successful innovation is to occur, some further implementation must take place,

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[3] See Alan R. Fusfeld, "How to Put Technology into Corporate Planning", Technology Review, 80, No. 6, for issues that need to be highlighted in a comparative technical review.

either by transfer of the interim results to manufacturing for embodiment in its process or for volume production activities, or by transfer to later stages of further development. All such later stages involve heavier expenditures and the post-project evaluation can be viewed as a pre-transfer screening activity.

(6) Project Transfer. If the project results survive this evaluation, transfer efforts take place (e.g., from central research to product department R&D, or development to manufacturing engineering).[4] The project's details may require further technical documentation to facilitate the transfer. Key technical people may be shifted to the downstream unit to transfer their expertise and enthusiasm, since downstream staff members, technical or marketing, often need instruction to assure effective continuity. Within the downstream organizational unit the cycle of stages may begin again, perhaps by-passing the earliest two stages and starting with project initiation or even project execution. This "pass-down" continues until successful innovation is achieved, unless project termination occurs first.

III. NEEDED ROLES

Assessment of activities involved in the several stage innovation process, as just described, points out that the repeated direct inputs of five different work roles are critical to innovation. The five arise in differing degrees in each of the several steps. Furthermore, different innovation projects obviously call for variations in the required role mix at each stage. Nevertheless, all five work roles must be carried out by one or more individuals if the innovation is to pass effectively through all six steps.

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[4] For further perspectives on project transfer see Edward B. Roberts, "Stimulating Technological Innovation: Organizational Approaches". Research Management, XXII, No. 6 (November 1979), 26-30.

The five critical work functions are:

- Idea Generating: Analyzing and/or synthesizing (implicit and explicit) information (formal and informal) about markets, technologies, approaches and procedures, from which an idea is generated for a new or improved product or service, a new technical approach or procedure, or a solution to a challenging technical problem.[5]
- Entrepreneuring or Championing: Recognizing, proposing, pushing, and demonstrating a new (his own or someone else's) technical idea, approach or procedure for formal management approval.[6]
- Project Leading: Planning and coordinating the diverse sets of activities and people involved in moving a demonstrated idea into practice.[7]
- Gatekeeping: Collecting and channeling information about important changes in the internal and external environments; information gatekeeping can be focused on developments in the market, in manufacturing or in the world of technology.[8]

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[5] Pelz, D.C. and Andrews, F.M., Scientists in Organizations (New York: John Wiley & Sons, 1966).

[6] Roberts, E.B. "Entrepreneurship and Technology". Research Management, 11, No. 4 (July 1968), 249-266.

[7] Marquis, D.G. and Rubin, I.M. "Management Factors in Project Performance". (Cambridge: M.I.T. Sloan School of Management, Working Paper, 1966).

[8] Allen, T.J., Managing the Flow of Technology (Cambridge: The M.I.T. Press, 1977); and Rhoades, R.G. et al., "A Correlation of R&D Laboratory Performance with Critical Functions Analysis". R&D Management, 9, No. 1 (October 1978), 13-17.

- Sponsoring or Coaching: "Behind-the-scene" support-generating function of the protector and advocate, and sometimes of the "bootlegger" of funds; the guiding and developing of less experienced personnel in their critical roles (a "Big Brother" role).[9]

Lest the reader confuse these roles as mapping one-for-one with different people, three points need emphasis: (1) some roles, e.g. idea generating, frequently need to be fulfilled by more than one person in a project team in order for the project to be successful; (2) some individuals occasionally fulfill more than one of the critical functions; (3) the roles that people play periodically change over a person's career with an organization.

Critical Functions

These five critical functions represent the various roles in an organization that must be carried out for successful innovation to occur. They are critical from two points of view. First, each role is different or unique, demanding different skills. A deficiency in any one of the roles contributes to serious problems in the innovation effort, as we shall illustrate below. Second, each role tends to be carried out primarily by relatively few individuals, thereby making even more unique the critical role players. If any one critical function-filler leaves, the problem of recruiting a replacement is very difficult--the specifics of exactly who is needed is dependent on usually unstated role requirements.

We must add at this point that another role clearly exists in all innovative organizations, but it is not an innovative role! "Routine" technical problem-solving must be carried out in the process of advancing innovative efforts. Indeed the vast bulk of technical work is probably routine, requiring professional training and competence to be sure, but nonetheless routine in character for an appropriately prepared individual. A large number of people in innovative organizations do very little "critical functions" work; others who are important performers of the critical functions also spend a good part of their time in routine problem-solving activity. Our estimate, supported now by data from numerous organizations, is that 70 to 80 percent of technical effort falls into this routine problem-solving category. But the 20 to 30 percent that is unique and critical is the part we emphasize.

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[9] Roberts, op. cit., p. 252

Generally, the critical functions are not specified within job descriptions since they tend to fit neither administrative nor technical hierarchies, but they do represent necessary activities for R&D, such as problem definition, idea nurturing, information transfer, information integration, and program pushing. Consequently, these role behaviors are the underlying informal functions that an organization carries out as part of the innovation process. Beyond the five above, different business environments may also demand that additional roles be performed in order to assure innovation.[10]

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[10] One role we have frequently observed is the "quality controller", who stresses high work standards in projects. Other critical roles relate more to organizational growth than to innovation. The "effective trainer" who could absorb new engineers productively into the company was seen as critical to one firm that was growing 30 percent per year. The "technical statesman" was a role label developed by an electronic components manufacturer which valued the ability of some engineers to generate a leadership technical reputation through authorship and presentation of advanced concepts to outside professional colleagues.

It is desirable for every organization to have a balanced set of abilities for carrying out these roles as needed but, unfortunately, few organizations do. Some organizations overemphasize one role, e.g. idea generating, and underplay another role, e.g. entrepreneuring. Another organization might do just the reverse. Nonetheless, technical organizations tend to assume that the necessary set of activities will somehow be performed. As a consequence, R&D labs often lack sensitivity to the existence and importance of these roles which, for the most part, are not defined within the formal job structure. How the critical functions are encouraged and made a conscious part of technology management is probably an organization's single most important area of leverage for maintaining and improving effective innovation. The managerial capabilities required for describing, planning, diagnosing problems and developing the necessary teamwork in terms of the people-functions demanded by an innovative program are almost entirely distinct from the skills needed for managing the technical requirements of the tasks.

Impact of Role Deficiencies

Such an analytic approach to developing an innovative team has been lacking in the past and, consequently, many organizations suffer because one or more of the critical functions is not being performed adequately. Certain characteristic signs can provide evidence that a critical function is missing.

Idea generating is deficient if the organization is not thinking of new and different ways of doing things. However, more often than not when a manager complains of insufficient ideas we find the real deficiency to be that people are not aggressively entrepreneuring or championing ideas, either their own or others'. Evidences of entrepreneuring shortages are pools of unexploited ideas that seldom come to a manager's attention.[11]

Project leading is suspect if schedules are not met, activities fall through cracks (e.g., coordinating with a supplier), people do not have a sense for the overall goal of their work, or units which are needed to support the work back out of their commitments. This is the role most commonly recognized formally by the appointment of a project manager. In research, as distinct from development, the formal role is often omitted.

Gatekeeping is inadequate if news of changes in the market, technology, or government legislation comes without warning, or if people within the organization are not getting the information that they need because it has not been passed on to them. When, six months after the project is completed, you suddenly realize that you have just succeeded in reinventing a competitor's wheel, your organization is deficient in needed gatekeeping! Gatekeeping is further lacking when the wheel is invented just as a regulatory agency outlaws its use.

Inadequate or inappropriate sponsoring or coaching often explains projects that get pushed into application too soon, or project managers who have to spend too much time defending their work, or personnel who complain that they do not know how to "navigate the bureacracy" of their organizations.

The importance of each critical function varies with the development stage of the project. Initially, idea generation is crucial; later, entrepreneurial skill and commitment are needed to develop the concept into a viable activity. Once the project is established, good project leading/managing is needed to guide its progress. Of course, the need for each critical function does not abruptly appear and disappear. Instead, the need grows and diminishes, being a focus at some point, but of lesser importance at others. Thus, the absence of a function when it is potentially very important is a serious weakness regardless of whether or not the role had been filled at an earlier, less crucial time. As a corollary, assignment of an individual to a project, at a time when the critical role that he provides is not needed, leads to frustration for the individual and to a less effective project team.

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[11] One study that demonstrated this phenomenon is Baker, N.R. et al., "The Effects of Perceived Needs and Means of the Generation of Ideas for Industrial Research and Development Projects". IEEE Transactions on Engineering Management, EM-14, (1967), 156-165.

Frequently, we have observed that personnel changes that occur because of career development programs often remove critical functions from a project at a crucial time. Since these roles are usually performed informally, job descriptions are made in terms of technical specialties, and personnel replacements are chosen to fill those job vacancies, rather than on their ability to fill the needs of the vacated critical roles. Consequently, the project team's innovative effectiveness is reduced, sometimes to the point of affecting the project's success. Awareness of which roles are likely to be required at what time will help to avoid this problem, as well as to allow people performing functions no longer needed to be moved to other projects where their talents can be better utilized.

IV. CHARACTERISTICS OF THE ROLE PLAYERS

Compilation of several thousand individual profiles of staff in R&D and engineering organizations has demonstrated patterns in the characteristics of the people who perform each innovation function.[12] These patterns are shown in Table 1, indicating which persons are predisposed to be interested in one type of activity more than another and to perform certain types of activity well. For example, a person who is theoretically-inclined and comfortable with abstractions feels better-suited to the idea generating function than someone who is very practical and uncomfortable with seemingly discrepant data. In any unit of an organization, people with different characteristics can work to complement each other. Someone good at idea generating might be teamed with a colleague good at gatekeeping and another colleague good at entrepreneuring to provide necessary supporting roles. Of course, each person must understand his own expected role in a project and appreciate the roles of others in order for the teaming process to be successful. Obviously, as will be discussed later, some people have sufficient breadth to perform well in multiple roles.

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[12] Section VI describes a methodology for collecting these data.

Table 1 underlies our conclusion that each of the several roles required for effective technical innovation presents unique challenges and must be filled with essentially different types of people, each type to be recruited, managed, and supported differently, offered different sets of incentives, and supervised with different types of measures and controls. Most technical organizations seem not to have grasped this concept, with the result that all technical people tend to be recruited, hired, supervised, monitored, evaluated, and encouraged as if their principal roles were those of creative scientists or, worse yet, routine technical problem solvers. But only a few of these people in fact have the personal and technical qualifications for scientific inventiveness and prolific idea-generating. A creative idea-generating scientist or engineer is a special kind of professional who needs to be singled out, cultivated and managed in a special way. He is probably an innovative technically well-educated individual who enjoys working on advanced problems, often as a "loner".

TABLE 1. CRITICAL FUNCTIONS IN THE INNOVATION PROCESS

PERSONAL CHARACTERISTICS	ORGANIZATIONAL ACTIVITIES
IDEA GENERATING	
Is expert in one or two fields	Generates new ideas and tests their feasibility
Enjoys conceptualization, comfortable with abstractions	Good at problem-solving
Enjoys doing innovative work	Sees new and different ways of viewing things
Usually is an individual contributor, often will work alone	Searches for the break-throughs
ENTREPRENEURING OR CHAMPIONING	
Strong application interests	Sells new ideas to others in the organization
Possesses a wide range of interests	Gets resources
Less propensity to contribute to the basic knowledge of a field	Aggressive in championing his "cause"
Energetic and determined; puts himself on the line	Takes risks
PROJECT LEADING	
Focus for the decision making, information and questions	Provides the team leadership and motivation
Sensitive to accommodating to the needs of others	Plans and organizes the project
Recognizes how to use the organizational structure to get things done	Insures that administrative requirements are met
Interested in a broad range of disciplines and how they fit together (e.g., marketing, finance)	Provides necessary coordination among team members
	Sees that the project moves forward effectively
	Balances the project goals with organizational needs

TABLE 1 (continued)

PERSONAL CHARACTERISTICS		ORGANIZATIONAL ACTIVITIES
Possesses a high level of technical competence Is approachable and personable Enjoys the face-to-face contact of helping others	GATEKEEPING[13]	Keeps informed of related developments that occur outside the organization through journals, conferences, colleagues, other companies Passes information on to others; finds it easy to talk to colleagues Serves as an information resource for others in the organization; i.e., authority on whom to see and/or what has been done Provides informal coordiantion among personnel
Possesses experience in developing new ideas Is a good listener and helper Can be relatively more objective Often a more senior person who knows the organizational ropes	SPONSORING OR COACHING	Helps develop people's talents Provides encouragement, guidance and acts as a sounding board to the project leader and others Provides access to a power base within the organization - a senior person Buffers the project team from unnecessary organizational constraints Helps the project team to get what it needs from the other parts of the organization Provides legitimacy and organizational confidence in the project

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[13] Our empirical studies have pointed out three different types of gatekeepers: (1) technical, who relates well to the advancing world of science and technology; (2) market, who senses and communicates information relating to customers, competitors and environmental and regulatory changes affecting the marketplace; and (3) manufacturing, who bridges the technical work to the special needs and conditions of the production organization. See Rhoades et al., op. cit.

The technical champion or entrepreneur is a special person, too--creative in his own way, but his is an aggressive form of creativity appropriate for selling an idea or product. The entrepreneur's drives may be less rational, more emotional than those of the creative scientist; he is committed to achieve, and less concerned about how to do so. He is as likely to pick up and successfully champion someone else's original idea as to push something of his own creation. Such an entrepreneur may well have a broad range of interests and activities; and he must be recruited, hired, managed and stimulated very differently from the way an idea-generating scientist is treated in the organization.

The person who effectively performs project leading or project managing activities is a still different kind of person--an organized individual, sensitive to the needs of the several different people he's trying to coordinate, and an effective planner; the latter is especially important if long lead time, expensive materials, and major support are involved in the development of the ideas that he's moving forward in the organization.

The information gatekeeper is the communicative individual who, in fact, is the exception to the truism that engineers do not read--especially that they do not read technical journals. Gatekeepers link to the sources of flow of technical information into and within a research and development organization that might enhance new product development or process improvement. But those who do research and development need market information as well as technical information. What do customers seem to want? What are competitors providing? How might regulatory shifts impact the firm's present or contemplated products or processes? For answers to questions such as these, research and development organizations need people we call the "market gatekeepers"--engineers or scientists, or possibly marketing people with technical background, who focus on market-related information sources and communicate effectively to their technical colleagues. Such a person reads trade journals, talks to vendors, goes to trade shows, and is sensitive to competitive information. Without him, many research and development projects and laboratories become misdirected with respect to market trends and needs.

Finally, the sponsor or coach may in fact be a more experienced, older project leader or former entrepreneur who now has matured to have a softer touch than when he was first in the organization. As a senior person he can coach and help subordinates in the organization and speak on their behalf to top management, enabling ideas or programs to move forward in an effective, organized fashion. Many organizations totally ignore the sponsor role, yet our studies of industrial research and development suggest that many projects would not have been successful were it not for the subtle and often unrecognized assistance of such senior people acting in the role of sponsors. Indeed, organizations are most successful when chief engineers or laboratory directors naturally behave in a manner consistent with this sponsor role.

The significant point here is that the staffing needed to cause effective innovation in a technical organization is far broader than the typical research and development director has usually assumed. Our studies indicate that many ineffective technical organizations have failed to be innovative solely because one or more of these five quite different critical functions has been absent.

Multiple Roles

As indicated earlier some individuals have the skills, breadth, inclination and job opportunity to fulfill more than one critical function in an organization. Our data collection efforts with R&D staffs show that a few clusters explain most of these cases of multiple role-playing. One common combination of roles is the pairing of gatekeeping and idea generating. Idea generating activity correlates in general with the frequency of person-to-person communication, especially external to the organization.[14] The gatekeeper, moreover, in contact with many sources of information, can often synergistically connect these bits into a new idea. This seems especially true of market gatekeepers, who can relate market relevance to technical opportunities.

Another role couplet is between entrepreneuring and idea generating. In studies of formation of new technical companies the entrepreneur who pushed company formation and growth was found in half the cases also to have been the source of the new technical idea underlying the company.[15] Furthermore, in studies of M.I.T. faculty 38 percent of those who had ideas they perceived to have commercial value also took strong entrepreneurial steps to exploit their ideas.[16] The idea generating-entrepreneuring pair accounts for less than one-half the entrepreneurs, but not the other half.

Entrepreneuring individuals often become project leaders, usually as what is thought to be a logical organizational extension of the effective selling of the idea for the project. And some people strong at entrepreneuring indeed also have the interpersonal and plan-oriented qualities needed for project leading. But on numerous occasions the responsibility for managing a project is mistakenly seen as a necessary reward for successful idea championing. This arises from lack of focus upon the functional differences. What evidence indicates that a good salesman is going to be a good manager? If an entrepreneur can be rewarded appropriately and more directly for his or her own function, many project failures caused by ineffective project managers might be avoided. Perhaps giving the entrepreneur a prominant project role, along with a clearly designated but different project manager, might be an acceptable compromise.

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[14] Allen, op. cit.

[15] Roberts, E.B., op. cit.

[16] Roberts, E.B. and Peters, D.H., "Commercial Innovations from University Faculty". Research Policy, in press.

Finally, sponsoring, while it should be a unique role, occasionally gives way to a take-over of any-or-all of the other roles. Senior coaching can degenerate into idea domination, project ownership and direction from the top. This confusion of roles can become extremely harmful to the entire organization. Who'll bring another idea to the boss, once he steals some junior's earlier concept? Even worse, who can intervene to stop the project once the boss is running amok with his new pet?

All of the critical innovative roles, whether played singly or in multiples, can be fulfilled by people from multiple disciplines and departments. Obviously, technical people--scientists and engineers--might carry out any of the roles. But marketing people also generate ideas for new and improved products, "gatekeep" information of key importance to a project--especially about use, competition and regulatory activities--champion the idea, sometimes sponsor projects, and in some organizations even manage innovation projects. Manufacturing people periodically fill similar critical roles, as do general management personnel.

The fact of multiple role-filling can affect the minimum size group needed for attaining "critical mass" in an innovative effort. To achieve continuity of a project, from initial idea all the way through to successful commercialization, a project group must have all five critical roles effectively filled, while also satisfying the specific technical skills required for project problem-solving. In a new high-technology company this critical mass may sometimes be ensured by as few as one or two co-founders. Similarly, an "elite" team, such as Cray's famed Control Data computer design group, or Kelly Johnson's "Skunk Works" at Lockheed, or McLean's Sidewinder missile organization in the Navy's China Lake R&D center, may concentrate in a small number of select multiple-role-players the staff needed to accomplish major objectives. But the more typical medium-to-large company organization had better not plan on finding "Renaissance persons" or superstars to fill its job requirements. Staffing assumptions should more likely rest on estimates that seventy percent of scientists and engineers will turn out to be routine problem-solvers only, and that even most critical role-players will be single dimensional in their unique contributions.

Career-Spanning Role Changes

We showed above how some individuals fulfill multiple critical roles concurrently or in different stages of the same project. But even more people are likely to contribute critically but differently at different stages of their careers. This does not reflect change of personality, although such changes do seem partly due to the dynamics of personal growth and development. But the phenomenon also clearly reflects individual responses to differing organizational needs, constraints and incentives.

For example, let's consider the hypothetical case of a bright, aggressive, potentially multiple-role contributor, newly joining a company fresh from engineering school. What roles can he play? Certainly, he can quickly become an effective routine technical problem-solver and, hopefully, a productive novel idea generator. But, even though he may know many university contacts and also be familiar with the outside literature, he can't be an effective information gatekeeper for he doesn't yet know the people inside the company with whom he might communicate. He also can't lead project activities. No one would trust him in that role. He can't effectively entrepreneur, as he has no credibility as champion for change. And, of course, sponsoring is out of the question. During this stage of his career, the limited legitimate role options may channel the young engineer's productive energies and reinforce his tendencies toward creative idea output. Alternatively, wanting to offer more and do more than the organization will "allow", this high-potential young performer may feel rebuffed and frustrated. His perception of what he can expect from the job and, perhaps more importantly, what the job will expect from him, may become set in these first few months on the job. Some disappointeds may remain in the company, but "turn off" their previously enthusiastic desire for multi-dimensional contributions. More likely, the frustrated high-potential will "spin-off" and leave the company in search of a more rewarding job, perhaps destined to find continuing frustration in his next one or two encounters. For many young professionals the job environment moves too slowly from encouraging idea generating to even permitting entrepreneuring.

With two or three years on the job, however, the engineer's role options may broaden. Of course, routine problem-solving and idea generating are still appropriate. But some information gatekeeping may now also be possible, as communication ties increase within the organization. Project leading may start to be seen as legitimate behavior, particularly on small efforts.[17] And the young engineer's work behavior may begin to reflect these new possibilities. But perhaps his attempts at entrepreneurial behavior would still be seen as premature. And sponsoring is not yet a relevant consideration.

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[17] One study showed that engineers who eventually became managers of large projects began supervisory experiences within an average of 4.5 years after receiving their B.S. degrees. Rubin, I.M. and Seelig, W., "Experience as a Factor in the Selection and Performance of Project Managers". IEEE Transactions on Engineering Management, EM-14, No. 3 (September 1967), 131-135.

With another few years at work, the role options are still wider. Routine problem-solving, continued idea generating, broad-based gatekeeping (even bridging to the market or to manufacturing), responsible project managing, as well as project championing may become reasonable alternatives. Even coaching a new employee becomes a possibility. The next several years can strengthen all these role options, a given individual tending usually to focus on one of these roles (or on a specific multiple-role combination) for this mid-career period.

Getting out of touch with a rapidly changing technology may later narrow the role alternatives available as the person continues to age on the job. Technical problem-solving effectiveness may diminish in some cases, idea generating may slow down or stop, technical information gatekeeping may be reduced. But market and/or manufacturing gatekeeping may continue to improve with increased experience and outside contacts, project managing capabilities may continue to grow as more past projects are tucked under the belt, entrepreneuring may be more important and for higher stakes, and sponsoring of juniors in the company may be more generally sought and practiced. This career phase is too often seen as characterized by the problem of technical obsolescence, especially if the organization has a fixation on assessing engineer performance in terms of the narrow but traditional stereotypes of technical problem-solving and idea generating. "Retooling" the engineer for an earlier role, usually of little current interest and satisfaction to the more mature, broader and differently directed person, becomes a source of mutual grief and anxiety to the organization and the individual. An aware organization, thinking in terms of critical role differences, can instead recognize the self-selected branching in career paths that has occurred for the individual. Productive technically-trained people can be carrying out critical functions for their employers up to retirement, if employers encourage the full diversity of vital roles.

At each stage of his evolving career an individual can encounter severe conflicts between his organization's expectations and his personal work preferences. This is especially true if the organization is inflexible in its perception of appropriate technical roles. In contrast, with both organizational and individual adaptability in seeking mutually satisfying job roles, the scientist or engineer can contribute continuously and importantly to accomplishing innovation. As suggested in this illustrative case, during his productive career in industry the technical professional may begin as a technical problem-solver, spend several years primarily as a creative idea generator, add technical gatekeeping to his performance while maintaining his earlier roles, shift toward entrepreneuring projects and leading them forward, gradually grow in his market-linking and project managing behavior, and eventually accrue a senior sponsoring role while maintaining senior project-program-organizational leadership until retirement. But this productive full life is not possible if the engineer is pushed to the side early as a technically obsolete contributor. The perspective taken here can lead to a very different approach to career development for professionals than is usually taken by industry or government.

V. MANAGING THE CRITICAL FUNCTIONS FOR ENHANCED INNOVATION

To increase organizational innovation, a number of steps can be taken that will facilitate implementation of a balance among the critical functions. These steps must be addressed explicitly or organizational focus will remain on the traditionally visible functions that produce primarily near-term incremental results, such as problem-solving. Indeed the "results-oriented" reward systems of most organizations reinforce this short-run focus, causing other activities to go unrecognized and unrewarded.

We are not suggesting that employees should ignore the problem-solving function for the sake of the other functions. Rather, we are emphasizing the need for a balance of time and energy distributed among all functions. As indicated earlier our impressions and data suggest that 70 to 80% of the work of most organizations is routine problem-solving. However, the other 20 to 30% and the degree of teamwork among the critical functions make the difference between an innovative and non-innovative organization.

Implementing of the results, language, and concepts of a critical functions perspective is described below for the selected organizational tasks of manpower planning, job design, measurement and rewards. If critical functions awareness dominated managerial thinking, other tasks, not dealt with here, would also be done differently, including R&D strategy, organizational development and program management.

Manpower Planning

The critical functions concept can be applied usefully to the recruiting, job assignment, and development or training activities within an organization. In recruiting, an organization needs to identify not only the specific technical or managerial requirements of a job, but also the critical function activities that the job requires. That is, does the job require consulting with colleagues as an important part of facilitating teamwork? Or does it require the coaching and development of less experienced personnel in order to insure the longer run productivity of that area? To match a candidate with the job, recruiting should also include identification of the innovation skills of the applicant. If the job requires championing, then the applicant who is more aggressive and has shown evidence of championing new ideas in the past should be preferred over the less aggressive applicant who has shown much more technically-oriented interests in the past.

As indicated above there is room for growth from one function to another, as people are exposed to different managers, different environments and jobs that require different activities. While this growth occurs naturally in most organizations, it can be explicitly planned and managed. In this way, the individual has the opportunity to influence his growth along the lines that are of most interest to him, and the organization has the opportunity to oversee the development of personnel, and to ensure that effective people are performing the essential critical functions.

Industry has at best taken a narrow view of manpower development alternatives for technical professionals. The "dual ladder" concept envisions an individual as rising along either "scientific" or "managerial" steps. Attempted by many but with only limited success ever attained, the dual ladder reflects an oversimplification and distortion of the key roles needed in an R&D organization.[18] As a minimum the critical function concept presents "multi-ladders" of possible organizational contribution; individuals can grow in any and all of the critical roles while benefitting the organization. And, depending on an organization's strategy and manpower needs, manpower development along each of the paths can and should be encouraged.

Job Design and Objective Setting

Most job descriptions and statements of objectives emphasize problem solving, and sometimes project leading. Rarely do job descriptions and objectives take into account the dimensions of a job that are essential for the performance of the other critical functions. Yet availability of unstructured time in a job can influence the performance of several of the innovation functions. For example, to stimulate idea generating some slack time is necessary so that employees can pursue their own ideas and explore new and interesting ways of doing things. For gatekeeping to occur, slack time also needs to be available for employees to communicate with colleagues and pass along information learned, both internal to and external to the organization. The coaching role also requires slack time, during which the "coach" can guide less experienced personnel. Table 2 elaborates our views on the different emphasis on deadlines (i.e., the alternative to slack time) for each of the critical functions and the degree of specificity of task assignments (i.e., another alternative to slack) for each function.

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[18] For a variety of industrial approaches to the dual ladder see the special July 1977 Issue of Research Management or, more recently, Research Management, November 1979, 8-11.

These essential activities also need to be included explicitly in the objective of a job. A gatekeeper would, for example, see his goals to include providing useful information to colleagues. A person who has the attitudes and skill to be an effective champion or entrepreneur could also be made responsible for recognizing good new ideas. This person might have the charter to roam around the organization, talk with people about their ideas, encourage their pursuit, or pursue the ideas himself.

This raises a very sticky question in most organizations: Who gets the credit? If the champion gets the credit for recognizing the idea, not very many idea generators will be eager to let the champion carry out his job. This brings us to the next item, measures and rewards.

TABLE 2.

JOB DESIGN DIMENSIONS

Critical Function / Dimension of Job	Idea Generating	Entrepreneuring or Championing	Project Leading	Gatekeeping	Sponsoring or Coaching
Emphasis on deadlines	Little emphasis; exploring encouraged	Jointly set deadlines emphasized by management	Management identifies; need strong emphasis	Set by the job, i.e., the person needing the information	Little emphasis
Emphasis on specifically assigned tasks	Low; freedom to pursue new ideas	High; assignments mutually planned and agreed by management and champion	High, with respect to overall project goals	Medium; freedom to consult with others	Low

Performance Measures and Rewards

We all tend to do those activities which get rewarded. If personnel perceive that idea generating does not get recognized but that idea exploitation does, they may not pass their ideas on to somebody who can exploit them. They may try to exploit them themselves, no matter how unequipped or uninterested they are in carrying out the exploitation activity.

For this reason, it is important to recognize the distinct contributions of each of the separate critical functions. Table 3 identifies some measures relevant for each function. Each measure has both a quantity and quality dimension. For example, the objective for a person who has the skills and information to be effective at gatekeeping could be to help a number of people during the next twelve months. At the end of that time, his manager could survey the people whom the gatekeeper feels he helped to assess the gatekeeper's effectiveness in communicating key information. In each organization specific measures chosen will necessarily be different.

Rewarding an individual for the performance of a critical function makes the function both more discussable and manageable. However, what is seen as rewarding for one function may be seen as less rewarding, neutral or even negative for another function because of the different personalities and needs of the role-fillers. Table 3 presents some rewards seen as appropriate for each function. Again, organizational and individual differences will generate variations in rewards selected. Of course, the informal positive feedback of managers to their day-to-day contacts is a major source of motivation and recognition for any individual performing a critical innovation function, or any job for that matter.

Salary and bonus compensation are not included here, but not because they are unimportant to any of these people. Of course, financial rewards should also be employed as appropriate, but they do not seem to be explicitly

TABLE 3.

MEASURING AND REWARDING CRITICAL FUNCTION PERFORMANCE

Critical Function / Dimension of Management	Idea Generating	Entrepreneuring or Championing	Project Leading	Gatekeeping	Sponsoring or Coaching
Primary contribution of each function for appraisal of performance	Quantity and quality of ideas generated	Ideas picked up; percent carried through	Project technical milestones accomplished; cost/schedule constraints met	People helped; degree of help	Staff developed; extent of assistance provided
Rewards appropriate	Opportunities to publish; recognition from professional peers through symposia, etc.	Visibility; publicity; further resources for project	Bigger projects; material signs of organization status	Travel budget; key "assists" acknowledged; increased freedom and use for advice	Increased freedom; discretionary resources for support of others

linked to any one innovative function more than another. Table 3 identifies the rewards that are related to critical roles.

VI. PERFORMING A CRITICAL FUNCTIONS ASSESSMENT

The preceding sections demonstrate that the critical functions concept provides an important way of describing an organization's resources for effective innovation activity. To translate this concept into an applied tool one would need the capability for assessing the status of an R&D unit in terms of critical functions. Such an assessment could potentially provide two important types of information. The first is input for management decisions about ability to achieve organizational goals and strategy. The second is information that can assist management and R&D professionals in performance evaluation, career development and more effective project performance.

Method of Approach

The methodology for a critical functions assessment can vary depending on the situation--size of organization, organization structure, scope of responsibilities, industry and technology characteristics. From experience gained with a dozen companies and government agencies in North America, the authors have found the most flexible approach to be a series of common questionnaires, developed from the replicated academic research techniques on innovative contributors, modified as needed for the situation. Questionnaires are supplemented by a number of structured interviews or workshops. Data are collected and organized in a framework that represents: (a) the critical functions; (b) special characteristics of an organization's situation; (c) additional critical functions required in the specific organization; and (d) the climate for innovation provided by management. (See Table 4 for a sample of the approach used in one of the questionnaires.) The result is a measure of an organization's current and potential strengths in each critical function, an evaluation

TABLE 4.

SAMPLE OF THE CRITICAL FUNCTIONS QUESTIONNAIRE[19]

Each respondent is asked to rate statements such as those below according to three separate criteria:

(1) the respondent's personal preference, (2) his perceived skills for performing each activity, and (3) each activity's importance in the person's present job. In the usual instrument 3 or 4 item sentences scattered throughout the questionnaire provide multiple indications for each critical role, thus assuring reliability of the assessment.

> Working as an effective, contributing member of a team in carrying out a task with one or more colleagues. (A)
>
> Creating or developing ideas that result in new programs or services. (B)
>
> Being a "one-stop" question-answering service for others by maintaining an in-depth competence in a few areas. (C)
>
> Acting as a link between my unit and users to insure that users' needs are being met. (D)
>
> Searching out or identifying unexploited ideas that can be developed into a new program or service. (E)
>
> Bringing people together and developing them into a smoothly working team. (F)
>
> Lending credibility or power to less experienced or less visible personnel so they may be more effective in the organization. (G)

The letters, shown in the above examples for the reader's guidance, indicate perceived ties to the several critical functions:

A - Problem-solving
B - Idea generating
C - Technical gatekeeping
D - Market gatekeeping
E - Entrepreneuring or Championing
F - Project leading
G - Sponsoring or Coaching

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[19] This sample is reprinted here with the permission of Pugh-Roberts Associates, Inc. which holds copyright on the questionnaire.

of the compatibility of the organization's R&D strategy with these strengths, and a set of personnel development plans for both management and staff that support the organization's goals.

This information is valuable for the organization and the individual. The organization first gains a complete and meaningful set of information on its own balance among the critical innovation skills. The match between the strengths and mix of these skills and the staffing requirements of present goals and strategy can then be evaluated. The assessment process also reinforces the explicit recognition of the need for performance of different types of innovation-enhancing skills in an effective R&D organization. For management this underlines the need for developing different expectations of a person's job and different ways of managing, motivating, and rewarding individuals in order to support the over-all strategy. Finally, it gives the organization a framework for considering how the strengths of different individuals should be combined to be consistent with a productive long-range R&D strategy.

For the individual, the results provide a broader view of the role of a professional in an R&D organization, increased sensitivity to his own functioning and to his and his colleagues' relative strengths, and a very persuasive rationale for teamwork--the use of multiple functions to move an idea forward. In addition, the assessment can assist the individual in eliminating or reducing a mismatch between his perceived skills and talents and the requirements of the job. (These mismatches are probably the single greatest factor lowering motivation of technical professionals.) The critical functions assessment helps by providing both managers and professionals working for them a clarified set of job dimensions appropriate to the innovation activity that can be used as a better base for performance evaluation, career planning, and the development of job expectations. It is then easier to recognize and work with individual differences and strengths that they may have already known existed, as well as being able to use new approaches and specific vocabulary to identify new strengths or personal goals.

One result of the assessment is a profile for the organization based upon the aggregate self-perceptions of the individual members. For validity, each of the self-reports is checked with the person's manager and with a set of colleague responses. Where differences exist they can then be reconciled.

Application of the Critical Functions Approach

To illustrate the kinds of empirical and managerial results deriving from a critical functions assessment, we present here some outcomes developed from one moderate sized R&D organization. The analysis in this company included three main lines of inquiry:

(a) identification of the balance the company desired to have among the critical functions;

(b) identification of existing strengths in each function;

(c) identification of the factors supporting and inhibiting the performance of each function in the R&D organization.

Balance Among the Functions. Based upon careful examination of the organization's goals and requirements as discussed earlier, the management team determined what would be an "ideal" number of staff highly skilled at performing each function. This was accomplished by looking at each group and subjectively assessing the number required for each function, given the goals and human and physical resources of that unit. Table 5 presents the management group's assessment of the ideal number performing each function. Table 5 also shows questionnaire results on the number of people appearing to have the skills and strengths needed to perform each function well in addition to those actually carrying out the critical roles.

TABLE 5.

"IDEAL" VS. ACTUAL DISTRIBUTION OF STAFF PERFORMING EACH CRITICAL FUNCTION AND PRINCIPAL STRENGTHS OF THE STAFF[20]

	Idea Generating	Entrepreneuring/ Championing	Project Leading	Technical Gatekeeping	Market Gatekeeping	Sponsoring/ Coaching
"Ideal"	6	11	17	5	14	4
Actual	5	5	11	9	12	3
Strength	10	9	6	12	4	11

Total Population = 90 Professionals

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[20] These data are drawn from Alan R. Fusfeld, "Critical Functions: The Key to Managing Teamwork in the Innovation Process", presented at Innovation Canada 1976. Numbers of "actuals" and "strengths" are not additive since many of the individuals sampled performed or were strong in more than one critical function. Most of the professionals performed no critical functions.

Factors Affecting the Balance. In addition, the R&D staff was asked to assess a number of factors affecting the performance of the critical functions. The data collection instrument we designed for this purpose we called "The Innovation Climate Questionnaire". The results of these data provided substantial insights into the causes of discrepancies between the ideal and actual balance among the functions. For example, the staff's perception that they did not have management skills, i.e., familiarity with management concepts and techniques, helps to explain why the "actual" number who are project leading is lower than the "ideal" number and the relatively few who report strengths in project leading. Another factor was the R&D staff's lack of understanding of what project leading/managing was expected in its new matrix organization. Market gatekeeping, on the other hand, was blessed with sufficient staff performing the function, but they seemed to be performing far in excess of their abilities. This was explained by the perception that this function was well recognized and well rewarded by upper management, who continually stressed the importance of being market-oriented.

Table 6 lists some of the factors serving to support and inhibit each of the critical functions in the organization studied.

Actions Taken. As a result of the analysis, multiple actions were taken and it is useful to consider some of them. The first action was that every first-line supervisor and above, after some training, discussed with each employee the results of the employee's critical functions survey. (In other companies employee anonymity has been preserved, data being returned only to the individual. In these companies employees have frequently used the results to initiate discussions with their immediate supervisors regarding job "fit" and career development.) The purpose of the discussion was to look for differences

TABLE 6·

ORGANIZATIONAL "CLIMATE" FACTORS AFFECTING THE CRITICAL FUNCTIONS IN ONE COMPANY

Function	Factors Supporting the Performance of the Function	Factors Inhibiting the Performance of the Function
Idea Generating	Well-recognized function Reasonable freedom Good linkages with the market	Tight resources Focus on the short-term
Entrepreneuring/ Championing	Freedom to act Recognition of function	High cost of failure Limited reward for risk taking Receives poor coaching
Project Leading/ Managing	Strong management support Freedom to act Clear goals	Low acceptance by outside units Lack of management skills High cost of failure
Technical Gatekeeping	Well known by peers Freedom to travel	Emphasis on measurable performance Emphasis on creating new ideas Physical design - distances Poorly recognized function
Market Gatekeeping	Well recognized function Ready market access	Poor customer credibility due to premature introduction of products
Sponsoring/ Coaching	Clear business goals	Function not recognized Lack of company growth strategy "Firefighting" orientation

in how the employee and his boss each perceived the employee's job skills and to engage in developmental career planning. The vocabulary of the critical functions plus the tangible feedback gave the manager and the employee a meaningful, commonly shared basis for the discussion.

Several significant changes resulted from these discussions. A handful of the staff recognized the mismatch between their present jobs and skills. With the support of their managers, job modifications were made. Another type of mismatch that this process revealed was between the manager's perception of the employee's skills and the employee's own perception. Most of the time the manager was underutilizing his human resources.

The data also prompted action to improve the performance of the project leading function. The insufficient number who saw themselves performing the function and the perceived lack of skills resulted in several "coaching" sessions by upper management, further role clarification, and increased upper management sensitivity to the support needed for project leading. These activities also involved personnel from outside units in order to develop broader support outside the technical organization for the project leading role.

Important changes were made in how the technical organization recruited. To begin with, the characteristic strengths behind each critical function were explicitly employed in identifying the skills necessary to do a particular job. This led to a framework useful for interviewing candidates to determine how they might fit into the present organization and how they saw themselves growing. Also, upper management became conscious of the unintended bias in the recruiting procedure that was introduced by the universities at which they recruited and by who did the company's recruiting. Personnel primarily interested in idea generating (i.e. senior researchers) did most of the university interviewing. They tended to try to identify and favored hiring other people interested in idea generating, and described the organization in terms of interest to those people. As a result of the analyses, upper management was careful to have a mix of the critical functions represented by the people interviewing job candidates.

Other values resulted from the analyses which were less tangible than the above but equally important. Jobs were no longer defined solely in technical terms, i.e., the educational background and/or work experience necessary. For example, whether or not a job involved idea generation or exploitation was defined, and these typical activities were included in the description of the job and the skills needed to perform it well. The objectives of the job, in the company's Management-by-Objectives (MBO) procedure, were then expanded to include the critical functions. However, since all five functions are essential to innovation and it is the very rare person who can do all five equally well, the clear need for a new kind of teamwork was also developed. Finally, the critical functions concept provided the framework for the selection of people and the division of labor on the "innovation team" that became the nucleus for all new R&D programs.

VII. SYNOPSIS

This article has examined the main elements of the technology-based innovation process in terms of certain usually informal but critical behavioral functions. The life cycle of activities encountered in an R&D project served to identify five critical roles as reoccurring: idea generating, entrepreneuring or championing, project leading, gatekeeping, and sponsoring or coaching. Organizational problems associated with weaknesses in the playing of each of these roles were described.

Each critical role was detailed in terms of representative activities during a project, and dominant characteristics of typical role players were presented from surveys conducted among many North American R&D/engineering organizations. Two key observations were that some unique individuals concurrently perform more than one of the critical roles, and that patterns of roles for an individual often change during a productive work career.

Managerial implications of the critical functions concepts were developed in regard to manpower planning, job design and objective setting, and performance measurement and rewards. These discussions provide a basis for design of a more effective "multi-ladder" system to replace many R&D organizations' ineffectual "dual ladder" systems.

Techniques employed in carrying out a critical functions assessment were then described, along with the results obtained at one medium-sized R&D organization. A combination of survey questionnaires and management workshops were used to develop, interpret and apply the critical functions data to organizational improvement.

The critical functions approach was conceived as embodying the essence of innovative work in a research and development process. But several years of development, testing and discussion of this perspective have led to broadened view and applications. Computer software development was an early area of extension of the methods, as was their use in an architectural firm. Recent discussions with colleagues suggest an obvious appropriateness for marketing organizations, with more difficult translation expected in the areas of finance and/or manufacturing. To the extent that innovative outcome, rather than routine production, is the output sought, we have confidence that the critical functions approach will afford useful insights for organizational analysis and management.

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